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RESEARCH NOTES

Excessive Pressure Drop Through a Bed of Stored Grain During Aeration

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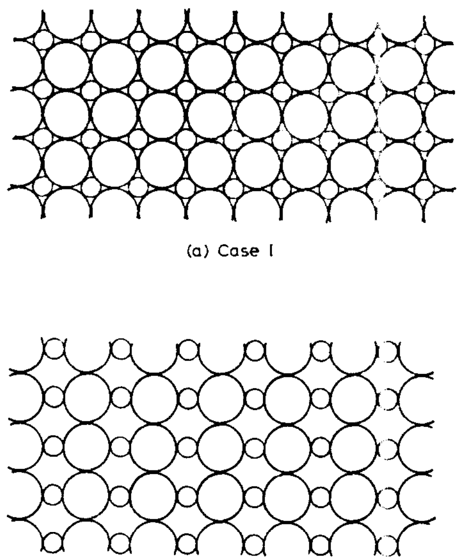
Foster[1] postulated that an excessive pressure drop through a bed of stored grain during aeration is due to filling of interstices among grains by fine particles. He further postulated that this mode of grain bed formation can be attributed to a greater overall drag being exerted on the fine particles that on the grain particles during their fall through the overboard space of the storage bin in the spread mode of filling, and that the drag is repeated cyclically when a mechanical spreader is employed. This greater overall drag on the fines, in turn, induces the fine particles to fall behind the grain particles, eventually filling the void created by the layers of the grain particles already formed in the bin.



(a) Case I

(b) Case II

Fig. 1. Model packed bed systems of grains and fines

The purpose of this note is to verify Foster's postulation through a model system study. Specifically two model systems, each containing large rigid spherical particles of a diameter, d_1 and small rigid spherical particles of a diameter, d_0, are considered. Case I depicted in *Fig 1 (a)* corresponds to the situation postulated by Foster. Case II depicted in *Fig. 1 (b)* corresponds to a situation in which no differential exists between the overall drag exerted on the fine particles and on the grains during their fall through the bin; thus, both the fine particles and grains have an equal probability of settling on the top of the grain bed already in existence in the bin.

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According to Ergun[2], the pressure drop of flow through a packed bed can be expressed as

$$\frac{\Delta P g_c}{L} = 150\frac{(1-\varepsilon)^2}{\varepsilon^3}\frac{\mu V_o}{d_p^{\,2}} + 1{\cdot}75\frac{1-\varepsilon}{\varepsilon^3}\frac{\rho V_o^{\,2}}{d_p}. \qquad \ldots(1)$$

where

d_p = effective diameter of particles, assumed as equivalent spheres,
g_c = gravitational constant,
L = height of the bed,
ΔP = pressure drop,
V_o = superficial fluid velocity measured at the average pressure,
ρ = density of fluid,
μ = absolute viscosity of fluid, and
ε = fractional void volume in the bed.

For laminar flow, the first term on the right side of the above equation predominates, i.e.

$$\frac{\Delta P g_c}{L} \simeq 150\frac{(1-\varepsilon)^2}{\varepsilon^3}\frac{\mu V_o}{d_p}. \qquad \ldots(2)$$

For turbulent flow, the second term predominates, i.e.,

$$\frac{\Delta P g_c}{L} \simeq 1{\cdot}75\frac{(1-\varepsilon)}{\varepsilon^3}\frac{\rho V_o^{\,2}}{d_p}. \qquad \ldots(3)$$

For Case I, the void fraction, as a function of the particle diameter ratio d_1/d_o, is

$$\varepsilon_{\mathrm{I}} = 1 - \frac{\pi}{6}\frac{(1+r^3)}{r^3}. \qquad \ldots(4)$$

where r is the diameter ratio of the large particle to the small particle, i.e.,

$$r = \frac{d_1}{d_o}. \qquad \ldots(5)$$

$r=\sqrt{2}+1$ is the minimum r that a small particle can be inserted into the pocket bounded by six large particles without displacing or replacing them. The corresponding void fraction is 0·4392. Since the effect of fine material packing is of interest to us, the size ratio r which should be considered may be greater than 100. In this instance, it is unrealistic to consider that only one small particle fills each pocket. We can visualize an aggregate of fine particles forming an equivalent small spherical particle. The size ratio r is now not the actual size ratio, but the ratio of the large particle to that of the equivalent small particle consisting of a number of fine particles. When $r\to\infty$, i.e. when the small particle is negligibly small, the packing arrangement reduces to the cubic with void fraction of 0·4764, if both large and small particles are approximately equal in number.

For Case II, the void fraction, as a function of the particle diameter ratio, is

$$\varepsilon_{\mathrm{II}} = 1 - \frac{\pi}{6}\frac{(1+r^3)}{(1+r)^3}. \qquad \ldots(6)$$

Assuming that the effective particle diameters for both cases are identical because the compositions of both cases are identical,

$$\frac{\left(\dfrac{\Delta P g_c}{L}\right)_{\mathrm{II}}}{\left(\dfrac{\Delta P g_c}{L}\right)_{\mathrm{II}}} \simeq \frac{(1+r)^6}{r^6}\,\frac{\left[1-\dfrac{\pi}{6}\dfrac{(1+r^3)}{(1+r)^3}\right]^3}{\left[1-\dfrac{\pi}{6}\dfrac{1+r^3}{r^3}\right]^3} \qquad \ldots(7)$$

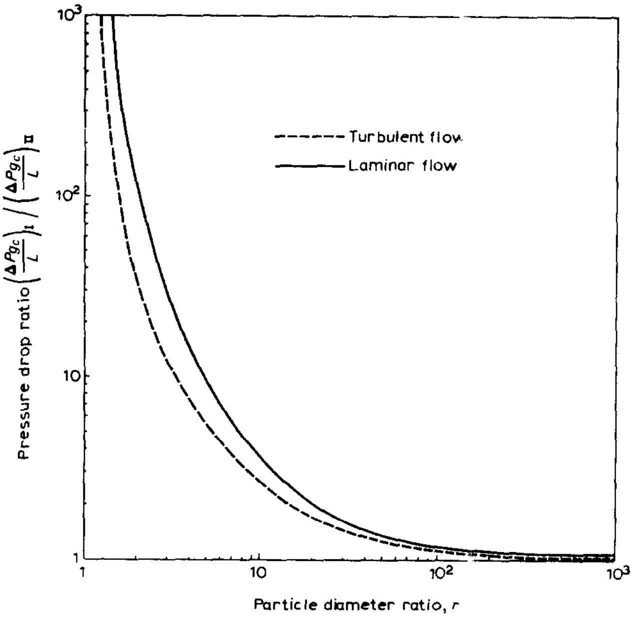

Fig. 2. Pressure drop ratio against particle diameter ratio through packed beds

when the laminar flow predominates, and

$$\frac{\left(\frac{\Delta P g_c}{L}\right)_{II}}{\left(\frac{\Delta P g_c}{L}\right)_{II}} \simeq \frac{(1+r)^3}{r^3} \frac{\left[1-\frac{\pi}{6}\frac{(1+r^3)}{(1+r)^3}\right]^3}{\left[1-\frac{\pi}{6}\frac{(1+r^3)}{r^3}\right]^3} \qquad \dots (8)$$

when the turbulent flow predominates. These expressions are illustrated in *Fig. 2.* For example, for $r=3$, Enq. (7) yields a value of 27·0 and Eqn. (8) a value of 11·4. Thus, our model system study indicates, at least partially, that Foster's postulation is valid.

REFERENCES

[1] **Foster, G. H.** Private communication, 1974

[2] **Ergun, S.** *Fluid flow through packed columns.* Chem. Engng Progr., 1952 **48** (2) 89